The current state of groundwater quality in the Waimakariri CWMS zone

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The current state of groundwater quality in the Waimakariri

Summary

Background  Environment Canterbury is working with the Waimakariri Water Zone Committee and the local community to improve water quality and quantity outcomes for the Waimakariri Canterbury Water Management Strategy (CWMS) zone. This is one of a series of reports being written to help inform the Zone Committee and the local community about the current state and trends in water quantity and quality within their zone.

The problem  Before embarking on a plan of action for where you want to go, you first need to know where you are. We needed to summarise groundwater quality data for the Waimakariri zone and its water management subzones and analyse any recent trends in nutrient concentrations.

What we did  We compiled what was known about how groundwater behaves in the Waimakariri zone: where it comes from; where it flows to and how it is connected with the surface water systems. We also looked at the distribution of rock and soil types, land uses and wastewater discharges in the zone. These can all influence the patterns we see in groundwater quality. We extracted groundwater quality data from Environment Canterbury’s water quality database and plotted them on maps.

Nitrogen, in the form of nitrate, is the nutrient we are most concerned about in groundwater. We looked at time series data for nitrate concentrations in long-term monitoring wells to see if and how these were changing in the zone.

What we found  Groundwater quality is generally very good and mostly meets drinking-water standards without any treatment. Poorer quality groundwater occurs naturally in some areas, often linked to organic-rich coastal soils and sediments in old swamp areas. In such places we find patches of groundwater with low or no dissolved oxygen (which we call reduced groundwater) together with elevated levels of dissolved iron, manganese and arsenic derived from the natural geology. Such conditions are also suitable for the mobilisation of phosphorus in groundwater.

Most of the wells in the Waimakariri zone are shallow and screened near the water table where unconfined groundwater is prone to contamination. Users of shallow private wells are most at risk from pathogens, especially near effluent disposal or animal grazing. Community supply protection zones have been established to protect the quality of the groundwater resource accessed for public supply of drinking-water, especially from microbial contamination. Nitrate concentrations in groundwater could pose a health risk to a small number of users of shallow domestic wells.

The Waimakariri zone has a long history of farming land uses. Some farming activities have released nitrogen to the environment which has leached into groundwater as nitrate. Where groundwater is dominantly recharged by seepage from hill-fed rivers or water races, the nitrate concentrations are typically low. Some nitrate is also assumed to be removed naturally by denitrification (a biogeochemical process that may occur in reduced groundwater). But in areas where there is neither surface water recharge nor denitrification, we see elevated nitrate concentrations in the groundwater.

Nitrate concentrations were already high in some monitoring wells when we first began regular sampling on the Ashley-Waimakariri plains in the 1980s. Since then nitrate concentrations have fluctuated, but there has been no overall long term trend. Intensification of land use in the Eyre River subzone may be imparting a slight increase in nitrate in some wells and springs in the Kaiapoi River catchment. Some of the nitrate load from the current land use may also still be moving through the groundwater to the surface waterways.

What does it mean?  Groundwater affected by natural contaminants (iron and manganese) cannot be managed by controls on land use, but can only be avoided or treated at the point of supply. Pathogens are generally controlled by good design and treatment in wastewater systems. Owners of shallow private wells should test their drinking-water supplies for E. coli or install a disinfection system.

Diffuse sources of nitrate leaching from land use are the main threat to groundwater quality in the Waimakariri zone. Any increases of nitrate in groundwater are likely to affect the ecology of spring-fed streams, especially the Cust Main Drain, Ohoka Stream and Kaiapoi River. Groundwater in parts of the Cust subzone are also close to the drinking-water limit for nitrate and some groundwater may become unpotable without decreasing nitrogen discharges. Groundwater has a greater capacity to assimilate nitrate in the Ashley and Coastal Wetland subzones. Groundwater is most susceptible to phosphorus discharges from land use in the Coastal Wetland subzone where reducing conditions commonly occur.
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1 Project background and purpose
Environment Canterbury is working with the Waimakariri Water Zone Committee and local community to develop recommendations for meeting their priority outcomes. These outcomes reflect the community’s goals for water management under the Canterbury Water Management Strategy (CWMS).

The community outcomes sought for the Waimakariri zone are:

- **Outcome 1** – The water quality and quantity of spring-fed streams maintains or improves mahinga kai gathering and diverse aquatic life.
- **Outcome 2** – The Ashley/Rakahuri River is safe for contact recreation, has improved river habitat, fish passage, and customary use; and has flows that support natural coastal processes.
- **Outcome 3** – The Waimakariri River as a receiving environment is a healthy habitat for freshwater and coastal species, and is protected and managed as an outstanding natural landscape and recreation resource.
- **Outcome 4** – The zone has safe and reliable drinking water, preferably from secure sources.
- **Outcome 5** – Indigenous biodiversity in the zone is protected and improved.
- **Outcome 6** – Highly reliable irrigation water, to a target of 95%, is available in the zone.
- **Outcome 7** – Optimal water and nutrient management is common practice.
- **Outcome 8** – There is improved contribution to the Regional Economy from the zone.

Groundwater is widely used as a source of water for public and private domestic supply, irrigation and commercial purposes in the Waimakariri zone. Groundwater also supports surface waterways and the ecosystems within them. Maintaining the quality of the groundwater for these uses must be balanced against the pressures of agricultural and urban development. The quality of groundwater is closely tied into meeting many of the outcomes, especially 1, 4, 7 and 8.

But before developing recommendations, we first need to understand the current situation. The purpose of this report is:

- to review available groundwater quality data
- to determine the current state of groundwater quality in the Waimakariri zone
- to analyse for trends in water quality and
- to provide explanations for the patterns we see.

2 Project area
The project area covers the Waimakariri zone as shown in Figure 2-1. The area includes the Ashley-Waimakariri plain, Lees Valley, and the Kowai and Loburn areas north of the Ashley River/Rakahuri. The Waimakariri Water Zone Committee have subdivided the Ashley-Waimakariri plain into four additional management subzones which we call the Eyre River, Cust, Ashley and Coastal Wetland subzones.
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2.1 General hydrology and topography

The topography of the project area ranges from hills and mountains, as high as 1800 m, in the northwest to flat coastal plains in the south and east.

The alpine Waimakariri River has its headwaters outside the project area, high in the Southern Alps/Kā Tiritiri o te Moana near Arthurs Pass. It forms the southern boundary of the zone all the way to the coast.

The Ashley River/Rakahuri is a hill-fed river. Its source is in the Puketeraki Range in the north west of the Waimakariri zone. It flows across the Lees Valley, a closed inland basin, where it is joined by several tributaries, before exiting on to the gently sloping plain via Ashley Gorge. The river then flows eastwards to the coast. South of the Ashley River/Rakahuri the topography comprises gently sloping plains of river gravel deposits. There is an area of rolling hill country at Mairaki Downs, north of the township of Cust and isolated hilly outcrops on the inland plains at Burnt Hill, View Hill and Starvation Hill. To the north of the Ashley River/Rakahuri is a steeper alluvial fan, the Loburn fan, drained by the Okuku River and other smaller tributaries of the Ashley. Figure 2-2 shows the locations of the main rivers and towns within the Waimakariri zone.

Two other important foothill rivers, the Cust River/Cust Main Drain and the Eyre rivers, flow across the Ashley-Waimakariri plain. The hill-fed Eyre River infiltrates to groundwater and is rarely flowing along its whole course. The Cust is also hill-fed in the upper reaches, but in the lower reaches it connects to the Cust Main Drain, which is channelized and fed by groundwater baseflow. Several spring-fed streams drain the coastal Ashley-Waimakariri plain.
2.2 Geology and soils

The Waimakariri zone is underlain by basement rocks of greywacke sandstone (Rakaia Terrane) that outcrop around the Lees Valley (Figure 2-3). These rocks are overlain by a sequence of sedimentary rocks (e.g. sandstone, siltstone, limestone, etc.) which were laid down in old marine and terrestrial environments more than 3 million years ago. Around this time, some of the hill areas around Oxford were formed by volcanic activity and still have outcrops of volcanic rocks. The Porters Pass-Amberley Fault zone passes through the hills on the southern side of the Lees Valley, while the Ashley-Loburn Fault System is associated with the rock outcrops of the Mairaki Downs and Starvation Hill. Tectonic activity has resulted in large scale deformations of the older rocks within the Waimakariri zone, which has shaped the topography and groundwater flow systems (Barrell and Begg, 2013; Mahon et al., 2016).

The dominant surface geological features of the Waimakariri zone are the alluvial sand and gravel deposits on the plains. These sediments were deposited in recent geological times, known as the Quaternary Period. They fill a basin structure that underlies the plains reaching its deepest point near Woodend/Tuahiwi (Jongens, 2011). Relatively older mid-Quaternary age river and outwash deposits occur on the Loburn Fan and near the Ashley River/Rakahuri around Cust/Cust Main Drain, while younger Quaternary age river gravels on the plains were deposited late in the last glacial period. The youngest river gravels are adjacent to our modern-day rivers.

From bore logs we know that the subsurface geology at the coast consists of a sequence of finer-grained estuarine deposits interfingered with the coarser river deposits. These are the northern extension of what is referred to as the ‘Coastal Confined Aquifer System’ in Christchurch. They were formed by the successive advance and retreat of the Canterbury coastline over past sea level changes.

The S-map soils database (Landcare Research 2016) shows very light and light soils covering the area between the Eyre and Waimakariri rivers and heavier soils north of the Eyre River (Figure 2-4). Not all of the area has been mapped by S-map which is why there is no soil cover shown for the Lees Valley.

The heavier soils mapped include poorly-drained soils over the Loburn fan, along the Cust River and on the coastal plains, where large areas were covered in wetlands in pre-human times (Statistics New Zealand, 2015). Much of the area north of the Ashley River/Rakahuri, the Mairaki Downs and the rolling hill country near Oxford are covered in fine-grained wind-blown deposits of loess. These loess soils typically contain a hardpan (fragipan) layer that limits opportunities for water to drain vertically down to the groundwater table, but instead promotes run-off to surface water.
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Figure 2-2: Location of major rivers, towns and landmarks in the Waimakariri zone
Figure 2-3: Geological map of the Waimakariri zone (simplified from QMap 1:250 000 geological map, Forsyth et al., 2008)
Figure 2-4: Soil cover map of the Waimakariri zone (simplified from Landcare Research, 2016)
3 Groundwater

3.1 Groundwater occurrence

Most of the accessible groundwater in the Waimakariri zone is hosted in unconsolidated Quaternary age sediments on the Ashley-Waimakariri plain. The water table is deeper in the Eyewell Forest area and shallower adjacent to the Eyre River and near the coast. The groundwater in Quaternary gravels shares a direct hydraulic connection to surface waters. Groundwater re-emerges in the gaining reaches of rivers, discharges to the spring-fed streams and some of the groundwater also flows to the sea (Etheridge and Wong, 2016).

Groundwater in the upper plains is hosted in thick river gravel deposits overlying the bedrock. In the lowland area, eastwards of around Mandeville, gravel deposits are interspersed with fine-grained layers of marine and estuarine sediments which thicken and become more continuous near the coast. Upwelling of deep groundwater is a natural phenomenon at the coast as the gravel layers pinch out to the east. Lower permeability sediments cause local confinement of the groundwater which results in artesian conditions and some of the deeper wells are free flowing (Etheridge, 2016).

Groundwater is also hosted in alluvial sediments in the Loburn and Kowai subzones, north of the Ashley River/Rakahuri. However, the aquifers here are generally less productive and wells have poorer yields than on the Ashley-Waimakariri plain. There is more surface runoff on the steeper slopes and poor drainage through loess soils, therefore groundwater recharge is limited. Only in the coastal part of the Kowai subzone are there good yields of groundwater where the Ashley alluvial fan extends northwards to Saltwater Creek. There are also groundwater resources in some of the older sedimentary rocks, such as the Kowai Formation at depth and around the inland margins of the Waimakariri zone, but this resource is not exploited to any significant extent at present.

We do not have very much groundwater information for the Lees Valley. The centre of the Lees Valley is infilled with shallow Quaternary deposits which likely contain groundwater in close connection with the rivers that flow through the valley. The bedrock surrounding and underlying the valley is relatively impermeable and acts as a barrier to groundwater flow. Therefore the valley is effectively hydraulically isolated from the aquifers on the plains. All groundwater leaving the Lees Valley must discharge to the Ashley River/Rakahuri and flow as surface water through Ashley Gorge.

3.2 Groundwater age

Around 80 samples from wells and springs in the Ashley-Waimakariri plains have been tested for groundwater age tracers (Stewart et al., 2002; van der Raaij, 2011). More samples were collected from spring-fed streams and drains in 2012 and 2016 (van der Raaij, 2013, 2016) for age tracer testing to investigate lag times for groundwater discharging to the streams.

Groundwater ages vary from very young, in the order of a few years, to very old. South of the Eyre River, the shallow groundwater is relatively old, in the order of 30 to 50 years mean residence time. Shallow groundwater north of the Eyre River had ambiguous age tracer estimates and the groundwater age has not been resolved.

Deeper groundwater has a mean residence time of more than 50 years throughput the Ashley-Waimakariri plain and the age increases towards the coast. In the coastal area, deep groundwater is generally too old to be reliably dated with tritium (i.e. likely greater than 80 years old), except for a wedge of younger groundwater near the Ashley River/Rakahuri (van der Raaij, 2011). The oldest deep groundwater near the coast has a radiocarbon age of almost 11 000 years.

Spring water is very young, especially near the Ashley River/Rakahuri where mean age of spring waters modelled from age tracer data is less than 3 years. Slightly older groundwater discharges to the Cust Main Drain and Ohoka River at Jacksons Road, which have estimated mean residence times of 9 to 9.5 years. The groundwater baseflow to the Kaiapoi River is estimated to be mostly around 5.5 to 6 years old (van der Raaij, 2016).

No age sampling has been undertaken in the Lees Valley or the subzones north of the Ashley River/Rakahuri.
3.3 Groundwater-surface water interaction

The Waimakariri River loses flow to groundwater, but most of this groundwater travels southwards towards Christchurch outside the Waimakariri zone (White et al., 2012). The Ashley River/Rakahuri interacts with the groundwater system in the Waimakariri zone along its length. Different stretches of the river lose and gain flow from the groundwater system (Farrow, 2016).

Most of the water from the Eyre River infiltrates to groundwater and the river rarely flows along its whole length. The Cust River is fed by rainfall in the hills. This river sometimes goes dry in the upper reaches but the lower channelized portion (the Cust Main Drain) receives more flow from groundwater as it crosses the plains.

There is also a high degree of connection between surface water and groundwater in Kowai, Loburn and Lees Valley subzones. Both the Okuku and the Garry rivers lose flow to groundwater across the Loburn fan (Chater, 2004) and the Whistler River loses flow across Lees Valley (NIWA, 2014). Groundwater must also re-emerge as surface water before exiting the valley at Ashley Gorge.

The interconnection of surface and groundwater affects the water quality we observe. Surface water comes from runoff from precipitation in the hills. It has a short residence time of only a few days, providing little opportunity for interaction between water and rocks. Surface water therefore has a chemical signature close to that of rainfall or snow. Groundwater recharge through the land surface has reacted with weathered minerals and organic matter in the soils which leaches dissolved salts and nutrients into the water. Groundwater has typical residence times of years to centuries in the subsurface also allowing for slowly dissolving minerals to react with the water. Groundwater with a river water provenance near the Ashley River/Rakahuri and the Eyre River has lower concentrations of dissolved salts and nutrients because it is dominated by a surface water chemical signature. But groundwater recharged by rainfall or irrigation through agricultural soils can have high concentrations of soluble nutrients, salts and even bacteria, depending on how much is present in the soil.

3.4 Groundwater recharge

The groundwater recharge sources in the Waimakariri zone include rainfall, irrigation return water, and rivers and water race losses.

Mean annual rainfall increases from the coast to the mountains, ranging from around 600 mm at Kaiapoi to around 1000 mm near Oxford and in the Lees Valley. The Loburn area receives around 800 mm per year on average. Some of the rainfall on the plains (approximately one third) recharges the aquifer and the rest is lost to evapotranspiration.

Irrigation also contributes to groundwater recharge through soil drainage of applied irrigation water (irrigation return water). Rainfall and irrigation together make up land surface recharge, which is thought to account for approximately 70% of the groundwater recharge over the Ashley-Waimakariri plains (Dodson et al., 2012).

The remaining recharge comes from rivers and races that lose flow by infiltration to the aquifer. The Ashley River/Rakahuri is a major source of recharge to the shallow part of the groundwater system between Rangiora and the coast. This river also recharges the groundwater in the Kowai subzone to the north towards Saltwater Creek. The Eyre River loses a large proportion of its flow across the Ashley-Waimakariri plain recharging the groundwater near the river. Leakage to ground from unlined water races were estimated to account for about 10% of the groundwater recharge between the Waimakariri River and the Ashley River/Rakahuri (Dodson et al., 2012).

Land surface recharge in the Loburn and Kowai areas is limited by the extensive coverage of loess soils. Infiltration is impeded by the low-permeability loess therefore much of rainfall received is diverted to runoff. Land surface recharge and river recharge are both likely to occur in the alluvial sediments along the main river channels, including the Okuku and Garry rivers (Chater, 2004).

Rainfall and river recharge from the Ashley River tributaries are the most likely mechanisms by which groundwater recharge occurs in Lees Valley. NIWA (2014) reported a flow loss of 210 L/s from the Whistler River between Whistler Gorge and the Ashley River/Rakahuri confluence in Lees Valley.
3.5 Groundwater flow direction

Groundwater flow paths determine the direction in which contaminants will be transported. Groundwater flow directions are inferable from piezometric contour maps. There have been several surveys of piezometric levels on the lower Ashley-Waimakariri plains (NCCB, 1982; NCCB, 1986, Dodson et al., 2012). Another piezometric survey was completed for the area north and south of the Waimakariri River in June 2016. These surveys show that groundwater flow paths diverge around the lower Ashley River/Rakahuri as it loses flow to the aquifer and converge around Kaiapoi where groundwater discharges to several spring-fed streams.

There are several mapped geological faults running through the Waimakariri zone (see Figure 2-3). Some of the faults may also control groundwater flow, especially where less permeable rocks have been juxtaposed with more permeable materials along a fault line, for example south of the Mairaki Downs.

We do not have any piezometric survey data for the Lees Valley, so our understanding of flow directions is less well defined. We assume that hydraulic gradient generally follows the surface topography. In the Lees Valley groundwater flow is presumed to converge at the gorge where the Ashley River/Rakahuri exits the valley.

3.6 Groundwater users

Groundwater allocation and usage volumes are discussed in detail in another report by Etheridge and Wong (2016). The breakdown of the type of water use for active and proposed wells in the catchment (as at April 2016 from Environment Canterbury’s Wells Database) is shown in Table 3-1. Figure 3-1 shows the locations of wells for each water use.

But the number of wells does not give any reflection of the volumes of groundwater abstracted. The largest numbers of wells are used for domestic and/or stock supply. Significant numbers of wells are also used for irrigation water and these abstract greater volumes of groundwater than the other uses combined. Etheridge and Wong (2016) estimated that, on average, total groundwater use between 2012 and 2016 was 66 million m$^3$/year. Irrigation use accounted for 69% of the abstraction.

Most of the wells used for domestic water supply are shallow (less than 30 m deep). A high proportion of the deeper wells are used for irrigation.

Table 3-1: Well use and depth breakdown for active and proposed wells

<table>
<thead>
<tr>
<th>Well depth:</th>
<th>&lt;10 m</th>
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<th>30 – 70 m</th>
<th>&gt; 70 m</th>
<th>Total*</th>
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<tr>
<td>Commercial / Industrial</td>
<td>6</td>
<td>11</td>
<td>2</td>
<td>8</td>
<td>33</td>
</tr>
<tr>
<td>Dairy Use</td>
<td>13</td>
<td>23</td>
<td>7</td>
<td>8</td>
<td>53</td>
</tr>
<tr>
<td>Domestic and Stockwater</td>
<td>83</td>
<td>876</td>
<td>265</td>
<td>54</td>
<td>1304</td>
</tr>
<tr>
<td>Domestic Supply</td>
<td>241</td>
<td>1265</td>
<td>255</td>
<td>40</td>
<td>1957</td>
</tr>
<tr>
<td>Irrigation</td>
<td>120</td>
<td>704</td>
<td>129</td>
<td>112</td>
<td>1073</td>
</tr>
<tr>
<td>Community Supply</td>
<td>8</td>
<td>38</td>
<td>12</td>
<td>30</td>
<td>89</td>
</tr>
<tr>
<td>Stock Supply</td>
<td>76</td>
<td>85</td>
<td>28</td>
<td>7</td>
<td>226</td>
</tr>
<tr>
<td>Total</td>
<td>547</td>
<td>3002</td>
<td>698</td>
<td>259</td>
<td>4735</td>
</tr>
</tbody>
</table>

* Total includes 229 additional wells for which no depth is recorded
3.6.1 Drinking water wells

Groundwater is used as a source of drinking-water supply throughout the Waimakariri zone. Waimakariri District Council operates 16 water supply schemes in the zone which are all sourced from groundwater and mostly untreated (Table 3-2, WDC, 2015). Ashley Rural Water Scheme is also supplied from groundwater sources on the north of the Ashley River/Rakahuri and is administered by Hurunui District Council.

Table 3-2: Waimakariri District Council Water Supply Schemes (as at June 2015)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Scheme Type</th>
<th>No. of Connections</th>
<th>Primary Source</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rangiora</td>
<td>On-demand</td>
<td>7042</td>
<td>Secure GW</td>
<td>None</td>
</tr>
<tr>
<td>Kaiapoi (including Pines/Kairaki)</td>
<td>On-demand</td>
<td>4710</td>
<td>Secure GW</td>
<td>None</td>
</tr>
<tr>
<td>Pegasus</td>
<td>On-demand</td>
<td>1307</td>
<td>Secure GW</td>
<td>Filtration &amp; chlorine</td>
</tr>
<tr>
<td>Woodend</td>
<td>On-demand</td>
<td>1075</td>
<td>Secure GW</td>
<td>Manganese filter</td>
</tr>
<tr>
<td>Oxford urban</td>
<td>On-demand</td>
<td>845</td>
<td>Secure GW</td>
<td>None</td>
</tr>
<tr>
<td>Waikuku Beach</td>
<td>On-demand</td>
<td>462</td>
<td>Unsecure GW</td>
<td>None</td>
</tr>
<tr>
<td>Cust</td>
<td>On-demand</td>
<td>141</td>
<td>Secure GW</td>
<td>None</td>
</tr>
<tr>
<td>Mandeville</td>
<td>Restricted</td>
<td>735</td>
<td>Secure GW</td>
<td>Chlorine &amp; pH</td>
</tr>
</tbody>
</table>

1 Restricted supplies are generally for rural properties. An agreed volume of water is supplied to the customer’s individual storage tank each day.
The current state of groundwater quality in the Waimakariri

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Scheme Type¹</th>
<th>No. of Connections</th>
<th>Primary Source</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxford Rural No. 1</td>
<td>Restricted</td>
<td>333</td>
<td>Infiltration gallery</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Oxford Rural No. 2</td>
<td>Restricted</td>
<td>333</td>
<td>Infiltration gallery</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Summerhill</td>
<td>Restricted</td>
<td>166</td>
<td>Secure GW</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Fernside</td>
<td>Restricted</td>
<td>85</td>
<td>Shallow well</td>
<td>Chlorine &amp; pH</td>
</tr>
<tr>
<td>West Eyreton</td>
<td>Restricted</td>
<td>68</td>
<td>Secure GW</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Ohoka</td>
<td>Semi-restricted</td>
<td>93</td>
<td>Shallow well</td>
<td>Chlorine &amp; pH</td>
</tr>
<tr>
<td>Poyntz's Road</td>
<td>Semi-restricted</td>
<td>79</td>
<td>Shallow well</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Garrymere</td>
<td>Semi-restricted</td>
<td>44</td>
<td>Shallow well</td>
<td>Chlorine &amp; pH</td>
</tr>
</tbody>
</table>

Figure 3-2 shows the location of all current community drinking-water supplies from groundwater and the protection zones drawn around them to manage discharges near the wells (AECOM, 2015)². There are also over 3000 active wells registered in our databases where the primary use is for private drinking water or combined drinking and stockwater supplies.

The drinking-water protection zones were defined according to Schedule 1 of the Canterbury Land and Water Regional Plan (LWRP). These are default provisional zones until the relevant water take consent is replaced, at which time the need for any refinement of the protection zone may be considered. The size of the default protection zone is related to the depth from which the groundwater is abstracted and the type of aquifer³. For shallower supplies the orientation of the protection zone is determined by the groundwater flow direction.

Rules in the LWRP control activities that could affect groundwater quality within the protection zones. Resource consent is usually required for point source discharges or land disturbance so that potential adverse effects can be assessed and mitigated. The primary aim of the protection zones is to protect drinking-water supplies from microbiological contamination. Diffuse sources of contamination and persistent chemical contaminants are not generally controlled by the protection zones.

² Some communities are supplied by several wells. The number of people supplied indicated in Figure 3-2 is for the whole supply, not the individual wells.
³ Unconfined and semi-confined aquifers have larger protection zones than confined aquifers.
The current state of groundwater quality in the Waimakariri Environment Canterbury Technical Report

Community supply wells
No of people supplied
- 25 to 100
- 101 to 500
- 501 to 5000
- Greater than 10000
- Unknown

Community Supply Protection Zones

Figure 3-2: Community supply wells and provisional drinking-water protection zones.

3.6.2 Groundwater-fed surface waterways

The major users of groundwater are the surface waterbodies fed from emerging groundwater. In the Waimakariri zone these include springs, wetlands, small lakes (some man-made), the gaining reaches of rivers such as the Ashley River/Rakahuri and the Cust Main Drain and spring-fed streams.

Etheridge and Wong (2016) estimate that on average the groundwater volumes discharging to surface water are three to four times greater than what is abstracted from wells. Long-term average surface water gains from groundwater measured in the Eyre River, Cust and Ashley subzones are about 215 million m$^3$/year. This excludes surface water gains in the Kowai subzone and some unmeasured flows.

A large number of springs, both permanent and intermittently flowing, have been mapped across the Waimakariri zone (Figure 3-3). Several springs are associated with the Ashley, Cust and Eyre river courses and more springs emerge from the high groundwater table in the coastal area. Prior to human settlement and man-made drainage networks, wetland covered a very large area from the springs west of Ohoka to the coast.

The Kaiapoi River (including Silverstream), Kaikainui Stream, Courtenay Stream, Ohoka Stream, North Brook, South Brook, Cam River/Ruataniwha, Waikuku Stream and several other tributaries and small waterways are all spring-fed streams that rely on groundwater discharge to sustain their flow in dry periods. Spring-fed streams have variable water quality and nutrient concentrations reflecting the quality of the upgradient groundwater that feeds the streams.
4 Groundwater quality

4.1 Overview of groundwater quality

The quality of groundwater is influenced by the chemistry of its recharge water, altered by natural reactions of the water with minerals and organic matter in the soils and below the ground. The reactions are often facilitated by naturally-occurring microorganisms (e.g. bacteria) that live in the ground.

In some areas, groundwater sourced from rainfall and rivers has very low concentrations of dissolved substances and is naturally very pure. But in other areas, groundwater can be of naturally poorer quality, especially where there is more reaction with soluble minerals and organic matter in the soils and aquifer.

The natural quality of groundwater is also altered by man-made pollutants which filter down in rainwater or irrigation water from the land surface to the groundwater table. These anthropogenic pollutants are said to have ‘leached’ into the groundwater. The most common pollutants we find in Canterbury groundwater are nutrients and pathogens (i.e. infectious microorganisms) from farming and effluent discharges.

In the following sections we consider some of the most common dissolved substances we find in groundwater in the Waimakariri zone. Section 5 discusses naturally-occurring substances in groundwater and Section 6 considers substances that leach from man-made sources and how these have been changing over time.

4.2 Groundwater quality monitoring

Environment Canterbury routinely collects groundwater samples from approximately 300 long-term monitoring wells sampled annually across the region, including around 30 wells the Waimakariri zone. The groundwater samples are sent to an accredited laboratory, where they are analysed for a range of...
dissolved substances, which we call chemical determinands. We measure the amount of each determinand by its concentration in a water sample (usually in milligrams per litre). These data are stored in Environment Canterbury’s water quality database.

Table 4-1 shows the comparison of results from the Waimakariri zone and the whole Canterbury region for the 2015 annual groundwater quality survey. Most of the concentrations of determinands in groundwater samples from the Waimakariri zone are fairly similar to the average for the whole of Canterbury. These concentrations are typical for the unreactive greywacke gravels aquifers of the Canterbury Plains.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Canterbury median</th>
<th>Waimakariri median</th>
<th>Waimakariri range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicarbonate (mg/L at 25°C)</td>
<td>62</td>
<td>55</td>
<td>19.4 to 143</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>7.6</td>
<td>6.8</td>
<td>2.8 to 71</td>
</tr>
<tr>
<td>Calcium (mg/L)</td>
<td>17.8</td>
<td>15.0</td>
<td>1.0 to 26</td>
</tr>
<tr>
<td>Iron (mg/L)</td>
<td>&lt;0.02</td>
<td>&lt;0.02</td>
<td>&lt;0.02 to 3.2</td>
</tr>
<tr>
<td>Magnesium (mg/L)</td>
<td>4.6</td>
<td>4.4</td>
<td>1.5 to 11.8</td>
</tr>
<tr>
<td>Nitrate Nitrogen (mg/L)</td>
<td>3.7</td>
<td>3.0</td>
<td>&lt;0.05 to 10.2</td>
</tr>
<tr>
<td>Reactive Silica (mg/L as SiO₂)</td>
<td>16.8</td>
<td>19.0</td>
<td>10.4 to 24</td>
</tr>
<tr>
<td>Sulphate (mg/L)</td>
<td>8.1</td>
<td>1.6</td>
<td>0.6 to 38</td>
</tr>
<tr>
<td>Total Ammoniacal-N (mg/L)</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt;0.01 to 0.24</td>
</tr>
<tr>
<td>Dissolved Reactive Phosphorus (mg/L)</td>
<td>0.006</td>
<td>0.008</td>
<td>0.003 to 0.073</td>
</tr>
<tr>
<td>Total Hardness (mg/L as CaCO₃)</td>
<td>65</td>
<td>55</td>
<td>8.5 to 113</td>
</tr>
<tr>
<td>Conductivity (mS/m)</td>
<td>19.7</td>
<td>17.0</td>
<td>8.7 to 49</td>
</tr>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>6.9</td>
<td>5.5</td>
<td>&lt;1 to 10.2</td>
</tr>
<tr>
<td>pH (field)</td>
<td>6.6</td>
<td>6.5</td>
<td>5.8 to 8.0</td>
</tr>
<tr>
<td>Water Temperature (°C)</td>
<td>12.4</td>
<td>12.7</td>
<td>11.1 to 15.0</td>
</tr>
<tr>
<td>E. coli (MPN / 100mL)</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1 to 14</td>
</tr>
<tr>
<td>Total Coliforms (MPN / 100mL)</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1 to 33</td>
</tr>
<tr>
<td>Number of wells</td>
<td>327</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

Looking at the range of concentrations for each determinand, there is some variation in groundwater quality in the Waimakariri zone. Some samples had very low concentrations of determinands. These are generally found in areas where the groundwater is sourced from river recharge or where alpine river water lost from irrigation races and is flowing through unreactive sands and gravels on the Ashley-Waimakariri plain.

Other samples have higher alkalinity, hardness, sulphate as well as iron and manganese concentrations which are linked to natural geology or groundwater conditions. These samples often come from wells in areas of historical wetlands, shown by the poorly-drained soils (blue shading) on the soils map in Figure 2-4. Natural organic carbon in the sediments slowly biodegrades and uses up the dissolved oxygen in groundwater. This in turn causes water quality problems, such as elevated...
concentrations of dissolved iron, manganese, ammoniacal nitrogen and sometimes arsenic, where these substances are present in the aquifer. Low oxygen (or reducing) groundwater environments can also decrease concentrations of nitrate nitrogen and sometimes sulphate. We will discuss these redox-controlled parameters later in this report.

As well as natural influences, some of the groundwater in the Waimakariri zone has elevated concentrations of other determinands, especially nitrate and faecal bacteria (E. coli), due to human activities.

4.3 Groundwater quality investigations

Apart from our routine, ongoing monitoring we also sample other wells and analyse the sample for selected chemical determinands during one-off investigations. Recently we have conducted several groundwater quality investigations in the Waimakariri Zone including:

- sampling of groundwater from deep and shallow wells along four transects across the Ashley-Waimakariri plain in 2010 (Dodson et al., 2012); and

We have not yet collected any groundwater samples from Lees Valley, which has very few wells. Because all groundwater must re-emerge to exit the valley, we assume that monitoring of the Ashley River/Rakahuri at Ashley gorge provides an indicator of overall groundwater quality in Lees Valley.

All other subzones have data from groundwater sampling, but we have fewer recent data from the Kowai subzone. A number of wells in the Ashley/Sefton area (north of the Ashley River/Rakahuri) were sampled by Environment Canterbury in May 2007. Wells in the Kowai subzone were also sampled for a student research project the following year (Dodson, 2009). Only one shallow well in this subzone at Saltwater Creek was regularly monitored between 1995 and 2012, when it was removed after a network review.

Data from these investigations has been incorporated into the maps in Sections 5 and 6.

5 Natural groundwater quality

5.1 Conductivity

Electrical conductivity (referred to as conductivity in this report) is a measure of the ability of water to carry an electrical charge. It is directly related to the concentration of charged dissolved substances (ions) in the water. Conductivity is a measure of salinity in the water.

Saline groundwater is not an issue for the Waimakariri zone where most of the groundwater is very dilute freshwater. Conductivity is mainly of interest for water quality assessment because it can be indicative of the groundwater recharge source. Conductivity can be affected by human activities, but mostly it is influenced by natural hydrogeological conditions. Low conductivity often indicates that river recharge is the dominant influence on groundwater quality. Recharge through soils tends to pick up more soluble ions and results in higher groundwater conductivity than recharge through well-flushed riverbed gravels. High conductivity can inform us of saltwater intrusion from the sea or estuaries into freshwater aquifers near the coast.

Figure 5-1 shows the maximum conductivity measured in groundwater in the Waimakariri zone. Groundwater close to the lower reaches of the Ashley River/Rakahuri show very low conductivity. The groundwater is influenced by the recharge of dilute hill-fed river water into clean river gravels with a very low content of soluble ions.

Groundwater conductivity is also low across the inland areas of the Ashley-Waimakariri plains. The Waimakariri Irrigation Limited (WIL) scheme has a large network of water races here which are supplied with alpine river water from the Waimakariri River. Leakage from the water race network is estimated to account for 1.2 m³/s of recharge to groundwater (Etheridge and Wong, 2016). Water race leakage also influences the groundwater conductivity near the races, resulting in low conductivity.

Higher conductivities may be associated with land use activities. Groundwater with high conductivity is found immediately downstream of old landfill sites near Kaiapoi. High conductivities may also be due
to natural sources: marine sediments and brackish surface water. This is probably why we see higher groundwater conductivity in the Kowai subzone where brackish surface from Saltwater Creek interacts with the groundwater. Local geology is responsible for groundwater having higher electrical conductivity around the Ashley-Sefton area, where the groundwater is slightly brackish.

![Map of Waimakariri Zone Groundwater Conductivity](image)

**Figure 5-1:** Maximum conductivity recorded in Waimakariri zone groundwater (1995 to 2016)

We have not seen any evidence of changes in conductivity or dissolved salts due to seawater intrusion along the coast in the Waimakariri zone. We monitor water levels at different depths and sample chemistry twice per year at a few of our coastal wells at Woodend Beach and Waikuku Beach for seawater intrusion monitoring. This is to ensure that groundwater abstraction is not causing seawater to encroach on freshwater aquifers.

### 5.2 Groundwater redox state

The reduction-oxidation (redox) state of groundwater is of interest because it controls the fate of several natural and man-made contaminants in groundwater. Redox reactions are important hydrogeochemical processes involving the transfer of electrons between chemical substances.

Carbon, oxygen, nitrogen, sulphur, iron, manganese and arsenic are all redox-active elements in groundwater. The transfer of electrons between these substances, often facilitated by microorganisms, determines which form(s) of these elements are stable – e.g. how much nitrogen is present as nitrate, nitrite, ammonia or nitrogen gas. This has important implications for the mobility and environmental impact of these substances. Many metals are more soluble, and therefore more mobile in groundwater, when they are in a reduced form (having gained electrons from another substance).

In groundwater we use the concept of ‘redox state’ to describe how the chemical system is poised in relation to transfer of energy via redox reactions. There are many different species that can undergo redox reactions, but for our purposes we have simplified the redox state into three main classes (after McMahon and Chapelle, 2008):
The current state of groundwater quality in the Waimakariri

- Oxidised (where dissolved oxygen is present);
- Reduced (where dissolved oxygen has been used up and other substances, such as nitrate, manganese, iron or sulphate, are the main reactive species); and
- Mixed (where multiple redox states can exist simultaneously as water from different states mixes or groundwater progresses from oxidised to reduced without reaching equilibrium);

Scientists have developed an algorithm to predict where these redox states occur in Canterbury based on factors such as geology, topography and soil characteristics (Close et al., 2016). Figure 5-2 shows redox state mapped by this method for shallow groundwater (less than 25 m deep) in the Waimakariri zone. The algorithm produces some artefacts (for example the strips of reduced groundwater at Eyrewell), but for the most part it agrees well with our observations of groundwater chemistry (as shown by the redox state at the wells in the map determined from their groundwater chemistry).

![Figure 5-2: Modelled groundwater redox states for shallow groundwater (data supplied by Close et al., 2016)](image)

This map is useful in that it helps to define areas where we are more likely or less likely to see different reactions happening in the groundwater. In the red ‘reduced’ zone, there is a greater chance of natural water quality problems such as poor taste or smell. Reduced groundwater can have high concentrations of dissolved iron and manganese, which can stain laundry and bathroom surfaces when these precipitate out upon exposure to air. Elevated concentrations of manganese or arsenic can also present a human health risk in these areas where they may exceed drinking-water maximum acceptable values (MAV) set by the Ministry of Health (2008).

Such problems are less likely in the yellow ‘oxidised’ zones. But the oxidised zones can have other water quality problems, such as a limited capacity to assimilate high concentrations of nitrate pollution in groundwater.
The groundwater redox state in the study area varies with depth. At greater depths there is a larger area of mixed redox state near the coast and more reduced groundwater at depth in the Oxford, Cust and Loburn areas. But the oxidised area on the Ashley-Waimakariri plains remains mostly the same to depths of greater than 100 m deep.

5.3 Dissolved oxygen

Dissolved oxygen is an important indicator of groundwater redox state. Oxygen is supplied to groundwater with recharge water (or by the less effective mechanism of diffusion of air into groundwater at the water table). Dissolved oxygen (DO) concentrations in groundwater, even at 100% saturation level, start off at around 10 to 11 mg/L. Groundwater containing dissolved oxygen is called ‘aerobic’ groundwater.

Dissolved oxygen is consumed by chemical reactions, but more significantly by biodegradation reactions, which are fuelled by organic matter. Low DO concentrations tend to correspond to areas of slow movement of old groundwater and/or where the aquifer contains an organic substrate, such as peat. On the whole, Quaternary-age outwash gravels are characterised by low organic matter content. Therefore aerobic groundwater is generally found at considerable depths in the Canterbury plains aquifer.

We measure dissolved oxygen using a portable field meter when we collect groundwater samples. This is so we can measure how much oxygen is present when the water comes out of the ground, before it has time to equilibrate with the air. Figure 5-3 shows the minimum DO concentrations we have recorded for groundwater in the Waimakariri zone. Many of the sites west of State Highway One have consistently high groundwater DO concentrations.

Groundwater with very low concentrations of dissolved oxygen that still has degradable organic matter present is a suitable environment for denitrification. Denitrification is a microbial process that removes dissolved nitrate from groundwater by converting it into nitrogen gases. Some areas of the Waimakariri zone, particularly in the Coastal Wetland subzone have low dissolved oxygen and organic-rich sediments and may be suitable environments for denitrification. The scale of denitrification capacity in the Waimakariri coastal area is the subject of a research investigation currently in process (as a case study under the Transfer Pathways Programme, a 3-year national multi-agency research programme).
The current state of groundwater quality in the Waimakariri

Figure 5-3: Minimum dissolved oxygen concentrations in groundwater (1995 to 2016)

5.4 Iron, manganese and arsenic

High iron, manganese and arsenic concentrations are usually natural and are often encountered in areas of reduced groundwater in Canterbury. The dissolved iron, manganese and arsenic originate from minerals in the aquifer sediments, which are mostly derived from the weathering of greywacke rock. Occasionally high iron and manganese can come from contamination, e.g. near old landfills; and high arsenic may be contamination from old sheep dips or wood treatment plants.

Figure 5-4 to Figure 5-6 show the maximum iron, manganese and arsenic concentrations measured in groundwater samples from wells in the Waimakariri zone. There are a number of sites where the iron concentrations exceed the guideline value (GV) of 0.2 mg/L set by the Ministry of Health, for aesthetic reasons) and some samples had very high iron concentrations. There are also a number of locations where the groundwater manganese concentrations exceed the GV of 0.04 mg/L. Some groundwater in the Woodend, Sefton and Oxford areas has also had manganese concentrations exceeding the MAV of 0.4 mg/L.

Twenty-two wells have yielded samples which exceeded the MAV of 0.01 mg/L for arsenic, mostly in the Woodend and Sefton areas. Most groundwater in the Waimakariri zone has no measureable arsenic because it is not present in the sediments over most of the area. Naturally-occurring arsenic, from the weathering of arsenic-bearing source rocks in the mountains, has accumulated in some areas of finer-grained estuarine deposits near the coast. Reduced groundwater conditions make the arsenic more mobile and limit arsenic being adsorbed by iron oxides, which are also soluble here.

Well-owners in areas of reduced groundwater should test their groundwater for manganese and arsenic and, if necessary, install treatment systems to ensure it is safe to drink.
The current state of groundwater quality in the Waimakariri

Figure 5-4: Maximum iron concentrations recorded in groundwater (1995 to 2016)

Figure 5-5: Maximum manganese concentrations recorded in groundwater (1995 to 2016)
6 Groundwater contamination

6.1 Types of contaminants

Most of the determinands we have discussed so far are found naturally in the environment. Human activities can make some of them more soluble in groundwater where they would naturally be present in immobile solid forms (e.g. minerals). Discharges of effluent with high organic load can help to create locally reduced groundwater, for example, and create associated water quality problems. But on the whole, substances such as iron, manganese and arsenic are not affected by land use activities.

There is another group of dissolved substances that are introduced on a large scale as pollutants to groundwater from human activities (called anthropogenic pollutants). In the Waimakariri zone we are most concerned about excess nutrients and microbial pathogens, which mainly come from human and animal effluent and agricultural land uses.

There are also anthropogenic pollutants such as heavy metals, hydrocarbons (petroleum products) and other organic chemicals which can be released to groundwater. These contaminants come from industrial wastewater, stormwater, leaking storage tanks, old landfills and other, typically urban, sources. Heavy metals and hydrocarbons in groundwater are usually investigated in areas where there has been a known spill or contaminated site, but are not part of our routine groundwater quality monitoring and investigations. Regional monitoring of these substances in Canterbury has found very low or non-detectable concentrations in groundwater (Hayward and Smith, 1999) and we have not focussed on these contaminants in this report.

The greatest contamination risk for drinking-water supplies from groundwater in the Waimakariri zone is pathogens. Pathogens are disease-causing bacteria, viruses and protozoa. These can all be transported in groundwater if they reach the water table (See Section 6.4).

Some wells in the Cust, Eyre River and Kowai subzones have exceeded the MAV for nitrate. This means there is a potential health risk to young babies if high nitrate-N groundwater is used as a...
drinking-water supply for pregnant women or for bottle-feeding. Nitrate will be discussed more detail in Section 6.5.

Contaminants in groundwater, particularly nutrients, can also cause problems when they are discharged to surface waterways. Nitrogen and phosphorus can cause nuisance growth of plants and algae in waterways and nitrate can be toxic to aquatic organisms at concentrations that would still be considered safe for drinking water.

### 6.2 Point source discharges

Discharges of wastewater, leachate from landfills, leaking storage tanks and other contaminants applied or released to land may introduce contaminants into groundwater. There are over 2000 active resource consents and permitted activity records in Environment Canterbury's database for discharges to land that occur in the Waimakariri zone.

Of the activity records, over 1700 represent known discharges of onsite wastewater (septic tanks). But these are only a portion of the total number of septic tanks likely to be present in the zone, many of which are allowed to be installed under permitted activity rules. We have used aerial imagery to conduct an inventory of dwelling in areas without connections to reticulated sewage networks to estimate the locations of these other septic tanks (Koh, 2016). The total number of septic tanks in the zone as at January 2016 was estimated at 5535 (Figure 6-1). New sites continue to be added as new houses are built outside of areas with reticulated wastewater.

![Onsite wastewater discharges](image)

**Figure 6-1:** Locations of human effluent discharge point sources (mostly septic tanks) which can contribute nutrients and pathogens to groundwater (sites estimated as at January 2016)
Septic tanks discharge nutrients (nitrogen and phosphorus) and pathogens (e.g. bacteria) to the subsurface. Based on the number of on-site systems in the Waimakariri zone we have estimated that around 41 tonnes/year of nitrogen and 9 tonnes/year of phosphorus are released to the environment from these point source discharges. Our estimates are based on the discharge assumptions used by Loe (2012), but we have slightly fewer septic tanks in this inventory than the 7454 tanks he estimated from consenting and census data. On a catchment scale, nutrient loads to groundwater from septic tanks are typically small in comparison to those that come from leaching from farming. An equivalent loss of nitrogen could come from around only 2000 ha of farmland (approximately 2% of the Ashley-Waimakariri plains) leaching an average of 20 kg nitrogen/ha/yr.

There are also community wastewater treatment facilities serving the larger urban areas such as Rangiora and Kaiapoi. Most of the wastewater collected by the Waimakariri District Council does not pose a risk to groundwater, because it is treated and discharged to Pegasus Bay via an ocean outfall pipeline. Smaller community treatment plants at Oxford and Woodend hold active consents to discharge treated domestic wastewater to land via spray irrigation after UV treatment (Oxford) and via settling ponds and wetlands (Woodend). Treatment helps to remove some of the contaminants before the discharge reaches groundwater.

The other consented and permitted point source discharges in the zone cover a range of wastes including animal effluent from farming; residential and industrial stormwater from urban areas; and other types of waste such as old landfills (Figure 6-2). Animal effluent is potential source of nutrients and pathogens in groundwater while stormwater and landfill leachate can carry a range of salts, heavy metals, hydrocarbons, pathogens or other contaminants. Loe (2016) is assessing nitrogen and phosphorus loads from the larger point source discharges in the Waimakariri zone.

![Figure 6-2: Locations of other discharge point sources which can contribute contaminants to groundwater](image-url)
6.3 Diffuse pollution

In addition to point sources, there are also diffuse sources of contamination that arise from normal agricultural activities. Approximately 80% of the population in the Waimakariri zone live eastward of Two Chain Road between the Waimakariri River and the Ashley River/Rakahuri (Sparrow, 2016). Apart from the urban areas of Kaiapoi, Rangiora and the smaller townships such as Oxford, Cust, Woodend, Waikuku and Sefton, the dominant land use in the Waimakariri zone is farming (Figure 6-3).

Controls on diffuse discharges from farming are relatively new in Canterbury. As of April 2016 there were only four land use consents for farming and two certificates of compliance for farming land use in Environment Canterbury’s consents database. Part of this project involves working with the community to develop solutions for managing diffuse contaminants from farming in the Waimakariri zone.
Figure 6-3: Land use in the Waimakariri zone (Landcare Research and AgResearch, 2016).
6.4 Pathogens in groundwater

*Escherichia coli* (*E. coli*) is a common gut bacterium of warm-blooded organisms and is used as an indicator organism for potential presence of pathogens. It is present in high numbers in faecal material and therefore indicates faecal contamination. Pathogens from human or animal waste can cause contamination of groundwater and make it unsuitable for drinking. *E. coli* can enter groundwater from septic tank discharges, effluent disposal or grazing animals in areas where it can infiltrate from the surface into the groundwater, especially after rainfall or with excessive irrigation. Microbiological contaminants like *E. coli* die off or are filtered out of solution in the subsurface, especially in the soil and unsaturated zone, so pathogens are naturally attenuated. Areas with thin soils and shallow groundwater can have rapid transport to the water table and are more prone to *E. coli* contamination. The MAV for *E. coli* is set at less than one per 100 mL of sample.

Our sampling for *E. coli* in groundwater is limited. We try to select wells for sampling where we know the wellhead is secure to ensure that pathogen-contaminated water cannot short-circuit down the well to the water table. Pathogens generally die off over time in the environment outside the animal gut. Even if the groundwater is prone to pathogen contamination we may not always detect the presence of *E. coli* if we do not sample at the right time. *E. coli* concentrations in groundwater are often highest after very wet periods when live bacteria are flushed rapidly to the water table. Our ongoing monitoring wells give us a more reliable estimate of the presence and concentrations of faecal bacteria than we can get from a one-off sample.

Figure 6-4 shows locations in the Waimakariri zone where we have sampled for *E. coli* (since 1999), and it indicates sites where *E. coli* have been detected in groundwater. Most of the data come from ongoing monitoring. We have used larger symbols to highlight sites where more than 10 samples have been tested. The sites with multiple detections have been labelled with the depth of the well. Additional one-off samples were collected recently near the spring-fed streams and Oxford.

All *E. coli* detections in the Waimakariri zone groundwater are from less than 50 metres deep in areas of rural land use. Septic tanks and grazing animals are likely to be present in these areas. We have not yet detected *E. coli* in wells in the Coastal Wetland or Ashley subzones or in deeper groundwater in the other subzones. Most repeat *E. coli* detections have been from wells less than 30 m deep.

Figure 6-4: Monitoring sites where groundwater samples have been tested for *E. coli* bacteria. Wells with more than 10 samples have larger symbols.
6.5 Nitrogen

6.5.1 Sources and transport of nitrogen

Nitrogen is a plant nutrient which is applied as a fertiliser (e.g. urea or organic nitrogen) on land to improve plant growth. Nitrogen also comes from grazing animals and effluent discharges. Nitrogen that is not taken up by plants can be converted to aqueous nitrate, a substance which is prone to leaching and highly mobile in groundwater.

Typically we report nitrate concentrations in terms of nitrate nitrogen (nitrate-N). This is useful as nitrate can be converted to other nitrogen compounds in the environment by naturally occurring bacteria, but the amount of nitrogen remains the same unless it is removed from the system.

The main forms of nitrogen in water are: nitrate, nitrite, ammonia and organic nitrogen. Dissolved inorganic nitrogen (DIN) refers to nitrate-N plus nitrite-N plus ammonia-N. Nitrate is the dominant form of DIN in natural oxygenated environments. That means that in groundwater, nitrate-N concentrations are roughly equivalent to concentrations of DIN. However, close to some discharge sources or where the water is low in dissolved oxygen, other forms of nitrogen may predominate.

6.5.2 Why we care about nitrate-N concentrations in groundwater?

Increasing the extent and/or intensity of agricultural land use generally increases nitrate-N concentrations in groundwater. Increasing nitrate-N concentrations are of concern because:

- High levels of nitrate-N in drinking water can be harmful to human health. The New Zealand drinking-water standards set a MAV for nitrate nitrogen at 11.3 mg/L (equivalent to 50 mg/L of nitrate), based on a risk to bottle-fed babies. Community and Public Health recommend that drinking-water with nitrate concentrations above MAV should not be used by bottle-fed babies less than six months old or pregnant women. The Ministry of Health also requires more frequent monitoring of public supplies when nitrate concentrations at the source exceed ½ MAV (5.6 mg/L).

- Nitrate-N can also be toxic for aquatic life in groundwater and groundwater-fed streams/rivers, having chronic (not acute) effects on aquatic life. The National Policy Statement for Freshwater Management (NPS-FM 2014, Ministry for the Environment) set a National Bottom Line for nitrate toxicity in rivers of 6.9 mg/L annual median and 9.8 mg/L annual 95th percentile nitrate-N.

- Nitrogen (N) is a plant nutrient and contributes to nuisance periphyton and macrophyte growth in streams/rivers, and associated deterioration of water quality (e.g. dissolved oxygen and pH) that can stress ecological values.

- Nitrogen is also perceived to be a factor in the growth of toxic cyanobacteria in waterways. Toxins from cyanobacterial blooms are harmful to human and animal health.

6.5.3 Nitrate leaching risk

Figure 6-5 shows a map of nitrate leaching risk determined by Webb et al. (2010). This risk is based on the types of soils present in the Waimakariri zone and their likelihood to provide conditions suitable retaining nitrogen in the soil zone. Soils with a very high risk are generally thin and free-draining and will leach more nitrate than deep or poorly-drained soils, which have low risk. The map only covers the flatter low-lying areas where S-map soil data are available. The mountain areas and Lees Valley are not covered.

Areas immediately adjacent to rivers often have very high risk of leaching as they are shallow and stony. Soils in the Eyre River and Loburn subzones are expected to have large areas of soils with a high or very high risk of leaching nitrate to groundwater. This agrees reasonably well with the elevated concentrations of nitrate-N we see in monitoring wells (see the following section). The Cust and Kowai subzones have soils of variable nitrate leaching risk. Mostly low or very low nitrate leaching risk soils cover the Coastal Wetland subzone, except for the very high risk dune sand deposits parallel to the coast. The very low leaching risk extends over a large area of historical swamp from Ohoka to the coast.
It is important to note that the risk map does not always agree with the nitrate-N concentrations we measure in groundwater. For example, some areas of high leaching do not have intensive land uses and will have low nitrate concentrations. Rivers or water races may provide recharge and dilution and therefore the concentrations measured will be lower in those areas. The maps will not provide information for deep groundwater. Areas of low leaching can also have higher nitrate-N concentrations than expected based on the risk maps. Nitrate can travel long distances in groundwater and therefore the nitrate observed in a well may be from up-gradient land use. The maps also do not account for bypass flow which can cause rapid deep drainage even in areas of low leaching risk.

![Nitrate leaching risk map](image)

Figure 6-5: Nitrate leaching risk map for soils in the Waimakariri zone
6.5.4 Nitrate-N concentrations in groundwater

Nitrate occurs naturally in groundwater, but generally at concentrations less than about 1 to 3 mg/L nitrate-N (Close and Smith, 2001; Chapelle, 1993; Madison and Brunett 1985 referenced in Hanson 2002). Recent analysis carried out by Morgenstern and Daughney (2012) shows that natural concentrations of nitrate-N in pristine New Zealand groundwater from pre-human occupation are likely to be below 0.25 mg/L. Based on correlations between groundwater age estimates and nitrate concentrations these authors found:

- nitrate-N concentrations between 0.2 and 2.5 mg/L tend to indicate low intensity impacts from about the 1880s onwards and
- nitrate-N concentrations above 2.5 mg/L generally occur in groundwater recharged after the 1950s, when land use began to intensify.

Figure 6-6 shows the highest nitrate-N concentrations recorded in groundwater for each well we have sampled in the Waimakariri zone since 1995. The reason for showing maximum concentrations is to emphasise areas where concentrations are always low. This indicates that the groundwater is derived from surface water recharge or from land with low nitrate leaching or from areas where there is denitrification occurring. There could also be a combination of these factors. Nitrate from the surface takes time to move down into the deeper parts of the aquifer and concentrations are generally highest near the water table.

In areas dominated by land surface recharge, rainfall or irrigation return water carries nitrate down into the groundwater. More intensive land uses with high stocking rates or high applications of fertiliser or effluent can result in higher concentrations of nitrate leaching to groundwater. Nitrate travels with the groundwater until it discharges in spring-fed streams, rivers or offshore (Etheridge, 2016). We see evidence of this process happening in the spring-fed streams west of Kaiapoi, for example, where elevated concentrations of nitrate-N from groundwater have been entering the Kaiapoi River/Silverstream (Greer, 2016).

The concentration of nitrate in the spring-fed streams is a mixture of the different nitrate concentrations recharged along the streamlines to the springs. Nitrate impacts are focussed at the water table, so wells and springs receiving groundwater from shallow flow will generally have higher nitrate concentrations than discharging deeper groundwater. Nitrate concentrations decrease if they are diluted with water of lower nitrate concentrations (e.g. from deeper groundwater, rivers and water races) or if denitrification occurs under reduced redox conditions. Recharge from the Ashley River/Rakahuri helps to keep nitrate concentrations low in the groundwater around Rangiora and there is also a strip of low nitrate concentrations along the Eyre River.

East of State Highway One, we find some of the lowest nitrate-N concentrations in the Waimakariri zone. Nitrate concentrations are kept low by a combination of factors including: more urban land uses and lower intensity farming; lower nitrate leaching risk through the soils (see Figure 6-5) and possible nitrate removal by denitrification in reduced groundwater (see Figure 5-2). South of Woodend, deep groundwater is under artesian pressure and upwelling deep groundwater is also likely to contain lower nitrate concentrations.

The highest groundwater nitrate-N concentrations in the Waimakariri zone have been found inland in the Ashley-Seton area (up to 26 mg/L nitrate-N) and near the Cust River at Springston (up to 16 mg/L). These are areas where there are low rates of land surface recharge and no river or water race dilution. Aquifer materials are probably less permeable; and nitrate from land use tends to accumulate instead of being flushed through. There may be point source discharges affecting the wells where these particularly high nitrate samples were taken, but the occurrence of high nitrate affects more than one well in the Ashley-Seton and Cust township areas and, in general, the land use is not more intensive than it is in other parts of the zone.

We know of at least 7 wells in the zone where concentrations of nitrate-N in groundwater have been above the drinking-water MAV of 11.3 mg/L sometime between 1995 and 2016. Two wells near Ashley-Seton have not been sampled since 1997, so we don’t know if the concentrations are still this high. Of the 97 wells we sampled for monitoring and investigations in 2015/16 only one shallow well between Oxford and Cust exceeded the MAV. Three other wells we sampled this year have also exceeded the MAV in the past, but their nitrate-N concentrations are currently less than 11.3 mg/L.
Lower concentrations of nitrate-N, but still above 3 mg/L are mostly found in groundwater between the Eyre and Cust rivers, near Eyrewell and in the lower plains around Mandeville North and Eyrton.

Figure 6-6: Maximum nitrate-N concentrations recorded in wells

6.5.5 Trends in nitrate concentrations in groundwater

Environment Canterbury samples groundwater on a regular basis in a number of wells, to monitor the nitrate-N trends over time. These wells are part of our regular, long-term state of the environment monitoring programme. We sample our long-term wells either annually or quarterly. In our water quality database we found data from 40 wells which have long-term monitoring for nitrate in the Waimakariri zone. Most of the wells are on the Ashley-Waimakariri Plain. We don’t have any quality monitoring wells in the Lees Valley and only two wells are monitored on the Loburn Fan.

From time to time the monitoring programme is revised when we review the data or wells become inaccessible, so not all of these wells are currently being monitored. Last year (2015), there were 21 wells in the zone where we had been sampling the nitrate-N concentration for the past 10 years or more.

We used a statistical test (Mann-Kendall test) to analyse for significant trends in the data over the past 10 years of monitoring from 2006 to 2015. The results are plotted on the map in Figure 6-7. Most of the long-term data show no trend in nitrate-N concentrations over this period. This is not to say that the nitrate-N concentrations are low or that they have always been constant; only that the concentrations have not been generally increasing or generally decreasing at most of our monitoring sites over the 10-year period we analysed. Groundwater nitrate-N data from two of the wells, at Eyrewell and Ohoka did have increasing trends. Concentrations have risen from around 6.5 mg/L to...
7.5 mg/L nitrate-N at our monitoring site in Ohoka and from 4.5 to 7 mg/L at Eyrewell over the past 10 years. We will discuss these trends in more detail in a later subsection on the lower Eyre River subzone. The data from the Springbank monitoring well near the Cust River (M35/6295) had a decreasing trend in nitrate-N concentrations and concentrations are now below the MAV, down from previous high concentrations near 16 mg/L.

Figure 6-7: Trends in nitrate-N concentrations from Environment Canterbury’s long-term monitoring wells (10-year trend 2006 to 2015)

But the trend statistics do not tell the whole story. We have also plotted time series graphs for the nitrate concentrations in our monitoring wells to look at long-term changes over time over different parts of the Waimakariri zone.

Figure 6-8 is one way we can show the overall changes in groundwater nitrate concentrations over time. It shows the median concentration from the collective of shallow wells (<40 m) that we sample annually in each of the four Waimakariri management subzones: Cust, Eyre River, Ashley and Coastal Wetland. The symbols in Figure 6-7 are colour coded to show which wells we have included in each group. We do not have enough monitoring wells or enough long-term records to plot median concentrations for the Kowai or Loburn subzones and we do not sample groundwater in the Lees Valley.
The current state of groundwater quality in the Waimakariri Environment Canterbury Technical Report

Figure 6-8: Median annual groundwater nitrate-N concentrations in the Waimakariri CWMS subzones aggregated from Environment Canterbury’s long-term monitoring wells.

Because we are mainly interested in the effects of land use on groundwater quality, we have only included the data from shallow wells (we used a cut-off depth of 40 m) which are most likely to be affected. Some wells were only sampled once per year (in the spring months from September to November) and we used all these data. For wells with more frequent samples we only used the sample collected closest to the springtime each year. Nitrate-N concentrations are typically higher in spring after the winter wet season flushes nitrogen down through the soils into the groundwater. So these plots are showing a picture of the higher nitrate-N concentrations we might measure over any year. Most of our long-term monitoring wells in the Eyre River subzone are north of the Eyre River and in the Cust subzone they are south of the Cust River. This distribution of wells may add a potential bias to the data for the zone as a whole.

We also show an average winter rainfall balance measurement (aggregated daily rainfall minus evapotranspiration from April to September) for climate stations in the Waimakariri zone. This gives us an indication of the relative amounts of rainfall recharge we might have expected in the season before the groundwater samples were taken.

Our graph also shows some water quality threshold values for comparison: the dark purple line is the drinking-water MAV (11.3 mg/L), the dotted and dashed green line is the national bottom line nitrate toxicity threshold from the NPS-NOF (6.9 mg/L) and the paler purple line is equivalent to ½ of the MAV (5.7 mg/L), sometimes adopted as a management threshold for average nitrate concentrations.

On average, groundwater nitrate-N concentrations have been relatively steady in the Waimakariri zone for the past three decades. The Ashley and Coastal Wetland subzones have had persistent low nitrate-N concentrations in their groundwater, typically less than 0.5 mg/L, even in shallow wells. We think that the concentrations are kept low by a number of factors, including: recharge of low nitrate water from the Ashley River/Rakahuri; low nitrate leaching from heavy soils; low intensity agricultural land use (most of the urban areas are in these subzones) and removal of nitrate in reduced groundwater.
The Eyre River and Cust subzones have had higher concentrations of nitrate-N in shallow groundwater and show more variability over the long term. There are some long periods where nitrate-N concentrations appeared to be decreasing (e.g. 1999 to 2005) and other times when the concentrations have been increasing (e.g. 2005 to 2010). Overall the median nitrate concentrations have tended to remain somewhere between 3 and 7 mg/L in the Eyre River subzone and between 6 and 9 mg/L in the Cust subzone. The Eyre River subzone median annual nitrate-N concentration has been below 5.7 mg/L since 1993, but the median for the Cust subzone has not been below this threshold in the past 28 years of monitoring. Median nitrate-N concentrations in shallow groundwater in the Cust subzone also exceeded the 6.9 mg/L nitrate toxicity threshold when monitoring began in the 1980s and have only infrequently dropped below this level.

The groundwater nitrate-N in the Cust and the Eyre River subzones show very similar long-term changes, which suggests that large scale controlling factors, such as changes in climate or land use, have a similar effect in both zones.

6.5.6 Nitrate in groundwater in the Kaiapoi river catchment

Greer (2016) reports high concentrations of dissolved inorganic nitrogen (DIN) at all monitored sites in the Kaiapoi River, the Cust River the Ohoka River and the South Brook: ‘Between 2011 and 2016 plant available nutrient concentrations were sufficiently high in all spring-fed streams in the Kaiapoi River catchment to allow macrophytes to proliferate’. Nitrate in groundwater is the major source of inorganic nitrogen in the spring-fed streams.

We have taken a closer look at the nitrate-N concentration trends in the lower part of the Eyre River subzone in recent years. This is where groundwater feeds into the spring-fed streams of the Kaiapoi catchment. Figure 6-9 shows the nitrate-N data from 2000 to 2015 for monitoring wells along two conceptualised flow lines in the lower part of the Eyre River subzone. We have also shown the surface water nitrate + nitrite-N concentrations for five sampling sites in the area.

Most of the groundwater samples show generally increasing nitrate-N and higher peak nitrate-N concentrations from around 2006. There are some exceptions, such as M35/0698 in Clarkville. This site is in the reduced groundwater zone and overlain by poorly-drained soils with low nitrate leaching risk. It is also near spring discharges where deeper groundwater (typically with lower nitrate-N) could be upwelling.

The seasonal high nitrate-N concentrations appear to be increasing in both our Swannanoa monitoring wells (M35/0132 on the northern flow line and M35/5440 on the southern flow line). Their peak concentrations were measured after the wet winters of 2013 (8.6 mg/L at M35/5440 in October) and 2014 (8.2 mg/L at M35/0132 in November). Concentrations of nitrate-N have also generally increased in the upgradient wells M35/8479 (West Eyreton) and M35/6385 (Eyrewell) since the early 2000s.

The downstream Kaiapoi River site (Island Road) had similar concentrations to the nearby shallow well M35/0698 since about 2004, but recently concentrations have been higher in the river than in the well. The increased nitrate appears to be coming from upstream, where our monitoring sites at Haywards Road and Harpers Road (Silverstream) have even higher nitrate concentrations. We do not have any long-term monitoring wells immediately upgradient of these spring-fed monitoring sites on the upper Kaiapoi River.
Figure 6-9: Groundwater nitrate-N concentration trends for wells along two flow lines in the Eyre River subzone
6.5.7 Nitrate-N in deeper groundwater

We have few long-term records of nitrate-N concentrations for deep wells in the Waimakariri zone (Figure 6-10). Nitrate-N concentrations generally decrease with depth below the water table on the inland plains. The elevated concentrations in groundwater from deep wells at Eyrewell and Cust show that nitrate-N can travel downward through the system and not all deep groundwater has low nitrate concentrations. Because we have only a short length of record for the inland deep wells, we do not have enough data to analyse for statistical trends in the data.

Deep groundwater at Kaiapoi does have low concentrations of nitrate-N, but we have seen a very slow, steady increase over time. Over nearly 30 years of monitoring the nitrate-N concentration has risen marginally from 1 mg/L to 1.4 mg/L (from well M35/0834, 136 m deep). Although our monitoring well is in the Coastal Wetland zone, where the nitrate leaching risk is low, this deep groundwater is sourced from old groundwater, some of which would have been recharged on the plains further inland.

At the coast, we also find that groundwater nitrate-N concentrations increase slightly with depth. At Woodend Beach the shallower groundwater mostly comes from the reduced groundwater zone and has non-detectable concentrations of nitrate-N. But samples from our 126 m deep well here have nitrate-N concentrations slightly above the detection limit. The deep groundwater is possibly also influenced by nitrate leached in the oxidised groundwater zone further up the plains and following a long flow path to the deeper well.

![Figure 6-10: Groundwater nitrate-N concentration trends in deeper monitoring wells](image)

6.6 Phosphorus

6.6.1 Sources and transport of phosphorus

Phosphorus is a plant nutrient which is applied as phosphate fertiliser to improve growth. It has a similar effect in surface waters, where increasing concentrations can result in excess growth and lead to eutrophication. There are no health-based limits set for phosphorus and therefore the main concerns are environmental.
In New Zealand, fertiliser use is a likely source of phosphorus pollution in agricultural areas (Rosen, 2001). Effluent is also very high in organic phosphorus and therefore effluent discharges to land will increase phosphorus in the soil. Phosphorus can also occur naturally in groundwater as it is present in some rocks and minerals. Older sedimentary deposits, especially those of marine origin, and volcanic rocks generally contain more phosphorus than the young braided river deposits that cover the plains. It can be difficult to distinguish phosphorus coming from land use from phosphorus that is naturally present in groundwater.

In groundwater, phosphorus is most commonly present as dissolved phosphate ions, which are readily available for plant growth. The determinand we measure in our groundwater samples is dissolved reactive phosphorus (DRP), using a method based on the reaction of phosphate with a colour changing reagent. Although the phosphate ion, like the nitrate ion, is negatively charged, it interacts quite differently with soil. Nitrate is prone to leaching, but phosphate adsorbs onto the soil particles and becomes immobile. Phosphorus also reacts with calcium, iron, or aluminium, reducing its solubility. Phosphorus loss to water is therefore commonly assumed to be mainly by surface runoff, where the phosphorus is carried as part of sediment into surface waters. Phosphorus can desorb from the sediment and result in nuisance growth in rivers and streams.

Research has shown that phosphorus can leach through soil if it is applied in excess of the soil’s capacity to retain it (Redding et al., 2006). This will depend on the type of soil and factors which affect soil sorption. Examples in Europe and the United States have shown that a build-up of excess phosphorus in soil over time will eventually lead to leaching into groundwater (Walters et al., 1996; Hesketh and Brookes, 2000).

McDowell et al. (2015) investigated the linkage between soil and surface and groundwater enrichment with phosphorus in New Zealand. They demonstrated that soil was especially enriched under dairying with high cow numbers and high phosphorus fertiliser use. They concluded that groundwater could contribute significant phosphorus to connected surface waters on soils prone to leaching and with intensive land use.

We have also found that phosphorus concentrations from both natural and man-made sources are linked to the redox state of groundwater (Scott and Wong, 2016). Most of Canterbury’s groundwater is oxidised (contains high dissolved oxygen) and phosphorus mobility is limited in this environment. If there is a source of phosphorus contamination, DRP is more likely to reach high concentrations if the groundwater becomes or remains reduced. This behaviour is broadly the inverse of nitrate, so we often see elevated DRP in areas where nitrate-N concentrations are low.

### 6.6.2 Phosphate leaching risk

Figure 6-11 shows the phosphate leaching risk determined by Webb et al. (2010). This risk is based on P-retention in various soil types and on soil thickness. Soils with a very high risk will leach more phosphate than soils with a very low risk. The map is not available for the Lees Valley, but does cover all areas with the most intensive land use.

This figure shows areas close to active river beds typically have the highest leaching risk because they have thin, stony soils with low phosphorus retention characteristics. But these do not show up as areas with high concentrations of DRP in our groundwater results (see the following section). A possible reason for this is because these are often areas where the river recharge of groundwater dilutes the nutrients leaching from land use. The groundwater is usually oxidised here and any DRP leached through the soil would likely be bound to the aquifer sediments.

There are areas of high phosphorus leaching risk mapped in the Coastal Wetland subzone, which do correspond to an area where we see very high DRP concentrations in groundwater. This is also an area where shallow groundwater is likely to be discharging to spring-fed streams and lakes. If the aim is to reduce phosphorus leaching and the resultant impact on surface waterways, then this is an area where management of phosphorus discharges will be important.
The current state of groundwater quality in the Waimakariri

6.6.3 DRP concentrations in groundwater

Figure 6-12 shows the highest DRP concentrations recorded in groundwater samples from the Waimakariri zone. There are no drinking-water limits for DRP, so we have adopted surface water quality thresholds to classify the data. For Canterbury streams and rivers, Stevenson et al. (2010) classed concentrations above 0.009 mg/L as ‘enriched’ and greater than 0.030 mg/L as ‘excessive’, based on Ministry for the Environment guidelines for recreational uses, which are linked to nuisance plant growth. We have also included another high class (>0.080 mg/L). This is not based on any environmental threshold, but is used to highlight the 10 wells with the highest recorded DRP in the zone.

Most of the wells with very high DRP (>0.080 mg/L) are located in the Coastal Wetland subzone (Figure 6-12). Very high DRP concentrations were found in both shallow and deep wells, ranging from a 12-m deep well at Saltwater Creek to very deep water supply wells at Pegasus (146 and 206 m deep).

Some of the high DRP in shallow wells could indicate contamination due to human activities, such as effluent discharges or leaking septic tanks. Much of the coastal area of the Waimakariri zone is covered by old estuary and swamp deposits. These deposits contain peat and old plant matter that are a natural source of dissolved phosphorus. Phosphorus in deeper groundwater near the coast is most likely coming from natural geological sources, such as marine sedimentary deposits.

The high organic content in the sediments near the coast also creates reduced conditions in soils and groundwater. Under these conditions, iron and manganese coatings on sediments dissolve. This
reduces the ability of the sediments to absorb phosphorus and more phosphorus can remain in dissolved form.

The Loburn and Cust subzones have a number of wells with elevated DRP. The source of DRP in some of these wells probably comes from the local soils and geology (e.g. the Kowai Formation). The Eyre River and Ashley subzones appear to have no geological source of phosphorus and generally have low DRP concentrations in the groundwater.

We have only recently started including DRP as a regular monitoring parameter, so we do not have enough data to look at long term trends in groundwater DRP concentrations in the Waimakariri zone.

Figure 6-12: Maximum DRP concentrations recorded in wells (1995 – 2016)

7 Groundwater quality by subzone

7.1 Waimakariri zone

Most of the wells in the Waimakariri zone are shallow and abstract groundwater near the water table where it is prone to contamination from land use activities. Large parts of the catchment have a long history of farming land uses (Sparrow, 2016) which have released nutrients and E.coli to the groundwater.

Groundwater nitrate-N concentrations in the Cust and Eyre River subzones were relatively high when we first started regular monitoring in the 1980s. Although concentrations have undergone shorter periods of increase and decrease there is no long-term, statistical trend in groundwater nitrate
concentrations in the Cust subzone. In the Eyre River subzone there are indications that land-use intensification has led to a slight increase in nitrate-N, which in some areas is trending upwards.

The geology of the hill areas (e.g. Oxford, Loburn, Kowai) is complex and likely affects the groundwater quality both by influencing recharge and groundwater residence times and by providing a source of more reactive minerals (e.g. phosphorus or soluble salts in marine sediments) than the greywacke-derived plains gravels. The coastal sedimentary geology, including organic-rich soils and peat lenses, hosts reduced groundwater which plays a role in controlling redox-active species. This can elevate natural concentrations of iron, manganese and arsenic but also reduce anthropogenic nitrate-N by denitrification.

Groundwater is vulnerable to bacterial contamination and E. coli bacteria are sometimes detected in shallow groundwater. Shallow groundwater, the source for most private well, is most at risk of contamination by pathogens, especially near effluent disposal or animal grazing. Infiltration galleries near rivers can also be susceptible to pathogens from river water. Community supply protection zones have been established to protect the quality of drinking-water from public supply wells against pathogen contaminants. Nitrate-N is also a potential health risk to a small number of shallow domestic wells, and has occasionally exceeded the MAV.

7.2 Lees Valley

- Recent gravels host most of the groundwater in the valley. Groundwater is recharged by local rainfall and streams and flow towards the Ashley River/Rakahuri. The Ashley River/Rakahuri exits the valley via the narrow Ashley Gorge and any groundwater (and dissolved nutrients) must re-surface.

- We have no data on past or current concentrations of nutrients in groundwater in Lees Valley other than the relatively low concentrations of nitrate and phosphorus measured in Ashley River/Rakahuri water samples taken at Ashley Gorge (Greer, 2016). Given the low intensity of land use, we anticipate the concentrations of nutrients in groundwater in the Lees Valley to be relatively low.

7.3 Loburn

- Thirteen wells and five river sites were sampled in an investigation in 2014 (Scott and Evans, 2015). We have been monitoring water quality from one well here since 1997 and a second long-term monitoring well was added to the Loburn subzone after the 2014 study.

- Recharge to groundwater is derived from land surface recharge and river losses, mainly from the Garry and Okuku Rivers. Land surface recharge is limited by loess cover on the hills. The Ashley River/Rakahuri does not lose water to the Loburn subzone.

- Shallow wells near rivers have low concentrations of nutrients (nitrate-N and DRP). Some wells have higher concentrations of nitrate-N between the rivers. Nitrate-N concentrations in our two long-term monitoring wells are variable, but have mostly been elevated in recent years (4 to 8 mg/L).

- The groundwater away from the rivers has relatively high concentrations of DRP. This is more likely to come from the local geology rather than from anthropogenic pollution.

- Iron and manganese exceed NZ drinking-water standard GV in some wells and one well exceeded the manganese MAV. The concentrations of iron and manganese increase with depth. These indicate reduced conditions in groundwater, particularly under loess soils.

7.4 Kowai

- Our groundwater quality data in the Kowai subzone were mainly collected between 2007 and 2009, with one monitoring well at Saltwater Creek continuing to 2012. We have no more recent data from this subzone.

- Low recharge through loess soils and thin aquifers with lower permeability make for poorer groundwater yields and higher groundwater conductivity in the downlands of the Kowai...
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subzone than in other parts of the Waimakariri zone. Better yields and quality are available near the Ashley River/Rakahuri in the Saltwater Creek area.

- The Kowai subzone also has some naturally poorer groundwater quality, including high conductivity; very high dissolved iron; and manganese and arsenic above MAV in some wells. But good quality groundwater can be found here too, especially within close proximity to the Ashley River/Rakahuri.

- Concentrations of nitrate-N have been elevated in groundwater near Ashley township (one well above MAV). Across the rest of the subzone groundwater nitrate-N was low.

7.5 Ashley

- We have been sampling one shallow well at Rangiora since 1986 and another since 1998. We also have a long-term monitoring well at Tuahiwi since 1995. A fourth shallow long-term well at Woodend was monitored from 1986, but was lost in the 2010/11 earthquakes. There have also been a number of other wells sampled here, including two north-south transects of shallow and deep wells in 2010.

- Recharge from the Ashley River/Rakahuri is the dominant influence on the quality of shallow groundwater in this subzone. Groundwater geochemistry indicates that deeper groundwater is probably sourced from land surface recharge moving eastward from inland areas.

- Ashley River recharge has very low conductivity and nutrient concentrations so the groundwater in the Ashley subzone has some of the best quality in the Waimakariri zone. We have not detected nitrate-N concentrations above 3 mg/L in wells in this subzone. This also has a positive impact on the quality of springs in the Ashley subzone feeding streams such as the Waikuku Stream.

- Along the eastern margins of the Ashley subzone we start to see the shallow groundwater becoming reduced with some elevated concentrations of dissolved iron.

7.6 Coastal Wetland

- The groundwater quality monitoring network includes 4 deep and 5 shallow wells in the Coastal Wetland subzone. Other groundwater sampling in the subzone has been done to investigate the occurrence of arsenic around Woodend in 2000 and transect sampling in 2010.

- Coarser gravels are interlayered with finer-grained deposits in the Coastal Wetland subzone. These sediments form the northern extension of the Coastal Confined Aquifer System of Christchurch. In this area groundwater discharges to several spring-fed streams, wetlands and small lakes. Shallow groundwater is locally recharged, but deeper groundwater is also influenced by land surface recharge from further inland. North of Woodend, deep groundwater mostly discharges offshore. Further south the offshore discharge is limited by lower permeability sediments and deep groundwater is under artesian pressure.

- Reduced groundwater is a feature of the Coastal Wetland zone. Many wells have low dissolved oxygen, elevated iron and manganese and very low nitrate-N concentrations. Nitrate-N leaching in this subzone is likely removed by denitrification. Arsenic is naturally present at levels above the MAV in some wells around Woodend and Waikuku.

- DRP is soluble in the reduced groundwater and some of the highest groundwater DRP concentrations in the Waimakariri zone are found in wells along the western margin of the Coastal Wetland subzone. The Coastal Wetland subzone is the area where management of phosphorus discharges is most important.

- We have not seen any evidence of changes in groundwater chemistry due to seawater intrusion along the coast in the Waimakariri zone.

7.7 Cust

- We monitor 7 shallow wells across the Cust subzone from Bennetts to Ohoka. Two wells have been sampled since 1986 and more monitoring wells were added in the 1990s. Since 2010 we have also been sampling a 100 m deep well at Cust. Other groundwater quality data come
from a west-east transect of shallow and deep wells across the subzone in 2010 and gap-filling sampling, especially in the upper Cust zone in 2016.

- Groundwater in the Cust subzone occurs in young alluvial sediments along the Cust River and older river gravel deposits. Faulting has exposed areas of lower permeability materials near Mairaki Downs and Cust township. Soils across the Cust subzone are variable from light to poorly-drained. Loess deposits near Cust and Oxford may limit groundwater recharge.

- Groundwater quality is also variable in the Cust subzone. Dissolved oxygen concentrations tend to be lower than in the Eyre River subzone to the south and there are areas where the groundwater has signs of mixed redox state (oxidised and reduced). A few wells have elevated iron and manganese concentrations and DRP typically associated with reduced conditions. These are found near Oxford at the upgradient end and Ohoka at the downgradient end of the subzone.

- Nitrate-N concentrations in groundwater around Cust have been the highest in the Waimakariri zone with a few wells exceeding MAV. The median annual concentration in our shallow Cust monitoring wells has been around 6 to 8 mg/L over the past 25 years of sampling. Long-term monitoring suggests there may have been a slight decline in nitrate-N in recent years. Nitrate-N also affects deeper wells. Our 100 m deep well screened 75 m below the groundwater table has concentrations between 4 and 5 mg/L nitrate-N.

7.8 Eyre River

- We currently monitor 9 shallow wells across the Eyre River subzone. We also have two deep wells (>100 m) at Oxford and Eyrewell that have been monitored since 2010. Other data has been collected along a west-east transect in 2010, an Eyrewell investigation in 2014/15 and gap-filling sampling in 2016.

- Groundwater occurs in thick alluvial gravel deposits beneath very light soils in the Eyre River subzone. The groundwater is recharged by rainfall, water race leakage and irrigation return water as well as losses from the intermittent Eyre River. The groundwater discharges to spring-fed waterways to the west of Kaiapoi.

- Redox conditions are predominantly oxidised, even at depths below 100 m. Problems with dissolved manganese are rare in this subzone and arsenic has not been detected in the groundwater. DRP concentrations are also relatively low.

- Nitrate-N concentrations on the whole are lower than in the Cust subzone. The median annual concentration in shallow Eyre River monitoring wells has been between 4 and 6 mg/L over the past 3 decades. There has been an increase in maximum nitrate-N concentrations in our shallow monitoring wells west of Kaiapoi with two 20 m-deep wells near Swannanoa peaking at over 8 mg/L nitrate-N in 2013.

8 Acknowledgements

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9 References

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